REDUCED GRAVITY SIMULATOR FOR STUDIES OF MAN'S MOBILITY

IN SPACE AND ON THE MOON

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Presented at the Human Factors Meeting

Dayton, Ohio
October 18-21, 1965

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INTRODUCTION

Due to the urgent nature of our national space program and the many unknown facets of man operating in space, there have been many parallel efforts carried out in recent years to develop methods for duplicating the environmental characteristics of space here on earth under controlled laboratory conditions. Many of these efforts have been fruitful and provided a spectrum of simulation facilities, each with unique performance characteristics and limitations. The purpose of this paper is to describe briefly the different facilities developed by the Spacecraft Research Branch of the Langley Research Center to study specifically the problems of man's mobility in space. We speak here of space as pertaining to any place outside the atmospheric veil of our planet; thus, we are concerned with situations ranging from man walking inside an orbiting space laboratory, to man landing a vehicle on the moon, or to man carrying heavy loads across the Martian terrain. I will attempt to discuss briefly the principal features of the three current specialized reduced-gravity simulators, to outline current research objectives, and to illustrate some typical test results performed in two of the facilities.

DISCUSSION OF FACILITIES AND RESEARCH OBJECTIVES

The simplest of the three simulators is the one commonly referred to as the lunar-walking simulator because it was developed specifically to study the problem of studying man's self-locomotive ability on the moon. There are, however, other applications of this facility which will be mentioned momentarily.

This simulator produces the gravitational equivalent of the moon, or any other place where the gravitational field is less than that of earth, by suspending the subject, as shown in figure 1, on his side so that he is free to generate body locomotive movements in a plane inclined with respect to earth's gravity vector. In the case of simulated lunar gravity, the body members move at about 80.5° relative to the vertical direction, so as to encounter a component equal to one-sixth of the gravity vector. As shown in figure 2, suspension is provided by a series of slings and cables attached to a lightweight trolley which travels freely along an overhead track. This track runs parallel with a walkway that is inclined 9.5° from the vertical and serves as the ground plane over which the subject travels. Other gravitational fields less than earth gravity are simulated merely by displacing the walkway parallel to the track so as to change the inclination of the subject and support cables to the appropriate angle. Of course, the inclination of the walkway would also be adjusted to match. To simulate the condition of weightlessness, the walkway

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would be moved directly under the track so that the cables are vertical and the subject horizontal.

Long cables of about 150 feet permit the subject to jump to maximum heights, up to about 12 feet, with only a slight distortion of the simulated gravity. This distortion is caused by the changing inclination angle of the cables as the subject swings out from the walkway. Corrections can be applied easily to the test results, when necessary, to compensate for the small gravity distortion present. The lightweight trolley is unpowered and employs low friction bearings, and, consequently, imposes a negligible restraint on the subject as he moves along the walkway.

Operation of the facility is simple and is best demonstrated by the following motion-picture scenes which illustrate a test subject walking, loping, and sprinting in the simulator adjusted to produce lunar gravity. The pictures are taken with a telephoto-camera mounted on the overhead gantry structure which supports the trolley track. The camera is pointed downward and operated by a cameraman so as to keep the subject within the field of view of the camera as he first walks, lopes, and then runs.

Objectives of the current research program for this facility are to evaluate performance of the lunar explorers both with and without their space suits while carrying various sizes of equipment loads. An additional program is being initiated to explore the use of back-pack type of rocket propulsion units to assist travelers over lunar terrain obstacles and to extend the traveler's range of operation.

Figure 3 summarizes some typical test results where the average variations of stride and stepping rate of three test subjects with speed of locomotion are shown for the simulated lunar gravity and are compared with those for the same three subjects performing in earth gravity. These tests were performed while wearing lightweight coveralls, rubber soled shoes, and a helmet. The comparison shows some significant differences between lunar and earth locomotion. For instance, both maximum lunar walking and running speeds were about 60 percent of the corresponding earth rates; also, for a given speed, the lunar stride was generally greater and the stepping rate was less than their earth counterparts. These data, along with the test subjects' comments, indicate that the effort involved in lunar activity is significantly less than that required for corresponding activity on earth.

In a subsequent paper, Dr. Walter Kuehnegger of the Northrop Space Laboratories will discuss further work under a NASA study contract utilizing a similar facility directed toward obtaining accurate metabolic, biomechanical, and other physiological data pertaining to lunar locomotion. Preliminary information from this work tends to substantiate the present test results.

The second type facility in use at Langley is a rotating space station simulator which employs a modification of the lunar-walking technique. Studies of man's ability to walk and work effectively in the environmental conditions of a space station rotating to produce artificial gravity are currently under way.

The setup of the simulator is illustrated in the photograph of figure 4. First, to produce the condition of weightlessness in space, the subject is supported in the same manner as previously discussed except that he is inclined on his side at 90° from the vertical so that all body members move at right angles to earth's gravity vector. The overhead trolley is mounted on a boom that follows the subject, so that he is free to walk around on the inner periphery of the circular walkway. Secondly, the condition of rotation is produced by an adjustable speed drive motor which rotates the platform on which the walkway and support boom are mounted.

Use of this facility is directed toward studying two aspects of space station operations. First is the evaluation of problems of vestibular disturbances which arise from the combination of angular motions about different axes resulting from work activity. These combined motions cause the vestibular sensors of the ears to generate distorting and nauseating reactions under some conditions. The objective of the research effort is to determine the effects of station diameter and rotational rate on threshold limits of the combined motions which generate the difficulties. Secondly, studies are being carried out to evaluate the effects of station diameter, rotational rates, and various station design features on the ability of the inhabitants to move from one portion of the station to another. The various design features include the use of stairs, ramps, ladders, poles, and hand grips.

The third simulator operated by the Spacecraft Research Branch is the lunar landing research facility, shown in figure 5, used to study the problems of flying a vehicle in lunar gravity and landing on the surface of the moon. For these studies a full-scale operational vehicle, similar to the Apollo Lunar Excursion Module or LEM, is flown by experienced research test pilots and astronauts under conditions of simulated lunar gravity. Simulation of lunar gravity is achieved by employing an overhead partial-suspension system which provides a lifting force by means of cables acting through the vehicle's center of gravity so as to effectively cancel all but one-sixth of earth's gravitational force. The lifting force and vertical alignment of the cables are controlled automatically through the action of servo-controlled hydraulic drive systems which power the overhead traveling bridge crane and dolly unit mounted on the large gantry structure. The bridge follows down-range motion of the vehicle, and the underslung dolly follows in the cross-range direction.

The cables are attached to the vehicle by means of a gimbal system which provides freedom of motion in pitch, roll, and yaw, as shown in the photograph of figure 6. This system consists of a swiveled-truss assembly directly over the cab and two vertical struts attached to the vehicle on its pitch axis. Load cells are carried in the vertical struts to sense cable force for the lift servo system, and cable angle sensors are mounted on the bottom of the dolly to provide error feedback signals for the bridge and dolly servo drive systems. Automatic braking equipment built into the servo drive units provides an extra safety feature unique to the particular facility. An aerial photograph of the facility is shown in figure 7 to illustrate the large size of the structure which can be compared with automobiles parked beside the operations building near the structure. The flight vehicle is on the ground beneath the bridge-crane unit at the left. The structure is 240 feet high and the vehicle can fly in a space of about 180 feet high, by 360 feet long, and 42 feet wide. This space is adequate for evaluating the vehicle handling characteristics for flight near the lunar surface and for touchdown.

The vehicle, shown next in figure 8, was constructed with many pieces of off-the-shelf equipment, such as the H-13 helicopter cabin and the H-34 landing-gear shock struts, so as to facilitate design, construction, and maintenance of the vehicle. Nitrogen gas is used for pressurizing the fuel system which supplies 90 percent hydrogen peroxide to the main lifting rocket motor assembly and the 20 attitude rocket motors located around the periphery of the vehicle frame. The cab has provisions for two test pilots, each with a complete set of controls. A common instrument panel is mounted between the two pilots, as shown in figure 9. Attitude controls at the right-hand seat consist of a set of standard foot pedals for yaw control and two-axis side-arm controller, of the pencil type, used for pitch and roll control. The left-hand seat is provided with a three-axis side-arm controller similar to the one intended for actual LEM use. Thrust of the main engines is controlled by either pilot with their left hand using the collective pitch levers. Weight of the vehicle is 12,000 pounds, of which about 3300 pounds is hydrogen peroxide fuel, giving a flight duration of slightly less than 3 minutes.

The objective of current research program employing this simulator is to evaluate the pilot handling-qualities criteria for manned lunar flight vehicles and determine the effects of various vehicle design and operational factors, such as out-of-the-window visibility and sharing of piloting tasks and responsibilities. This effort is being applied directly to the Apollo Lunar Excursion Module and is also aimed at providing basic information for second generation projects likely to follow the Apollo mission. The present vehicle, which was designed and built at least 1 year before the LEM concept became an approved program, bears a close family resemblance to the LEM arrangement, as illustrated in the sketch of figure 10, and duplicates many of the pertinent LEM system characteristics. However, so as to provide an even closer simulation, steps are currently under way to revise the vehicle to include an exact replica of the interior arrangement of the LEM cab. Subsequently, major modifications to the vehicle will be made so as to evaluate various other possible configurations for a second generation type vehicle. By making only minor adjustments in the servo system electronics, this facility can be adapted to study similar type problems for the conditions of space flight and landing on other planets such as Mars.

Preliminary results from the current flight-test program, which has provided over 37 flights with a total time in simulated lunar gravity of about 2 hours, show that the vehicle can be controlled and landed safely with characteristics matching those of the LEM vehicle. These initial flights have been performed using Langley research test pilots and the current program includes the use of the astronauts to provide a direct input of their experience and background for this program, as well as to provide them with some realistic-type lunar flight experience prior to their actual lunar mission.

SUMMARY

In summary, we have reviewed three unique reduced-gravity simulators currently in use at the Langley Research Center and discussed briefly their application. It must be remembered that these facilities were built to study particular problems but as these problems are resolved the features and modes of operation of the facilities most likely will be altered so as to make them useful tools for studying new and as yet unforeseen problems we will be encountering as we continue in our quest of space.

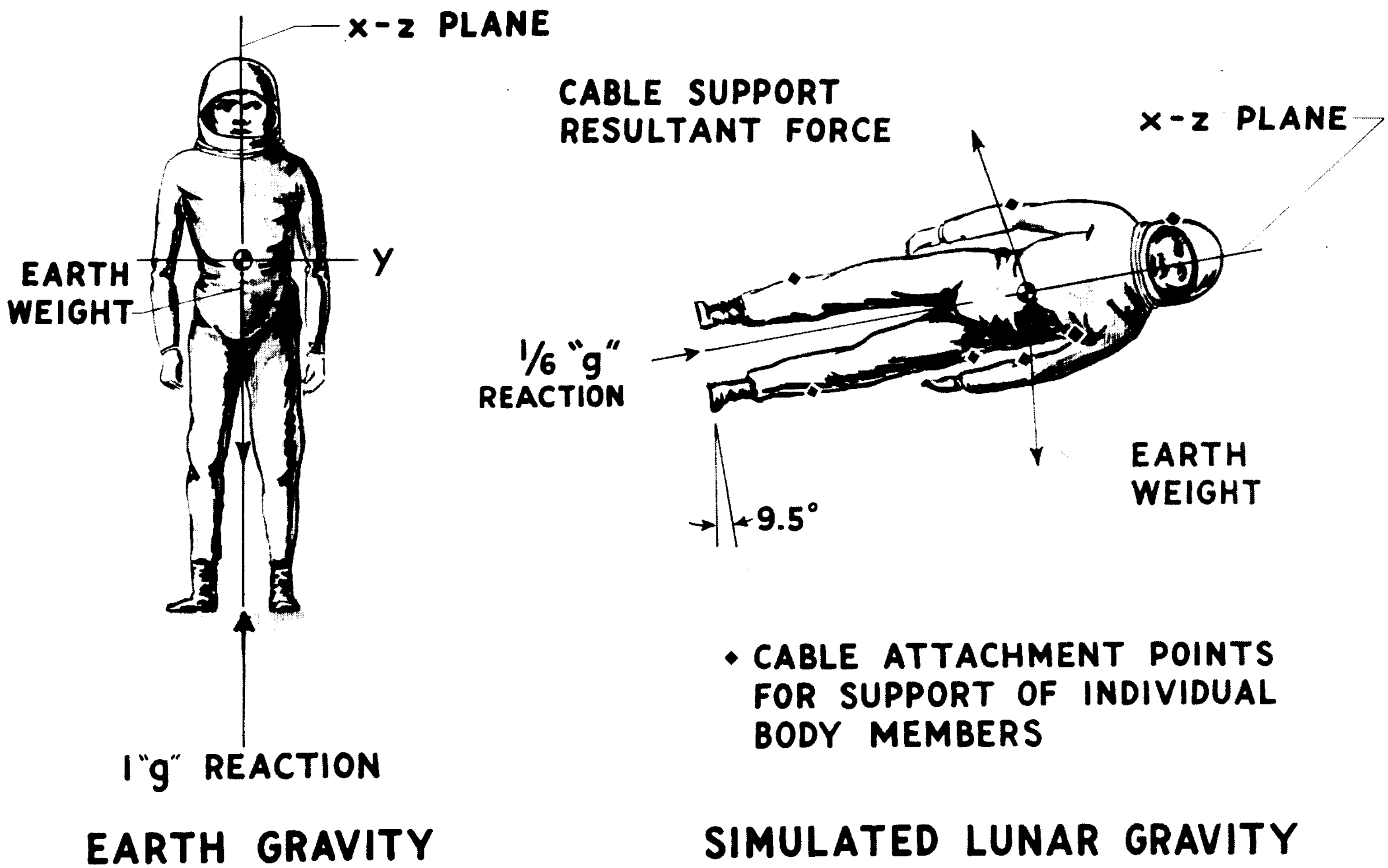

Figure 1.- Illustration of lunar gravity simulation technique for self-locomotive studies.

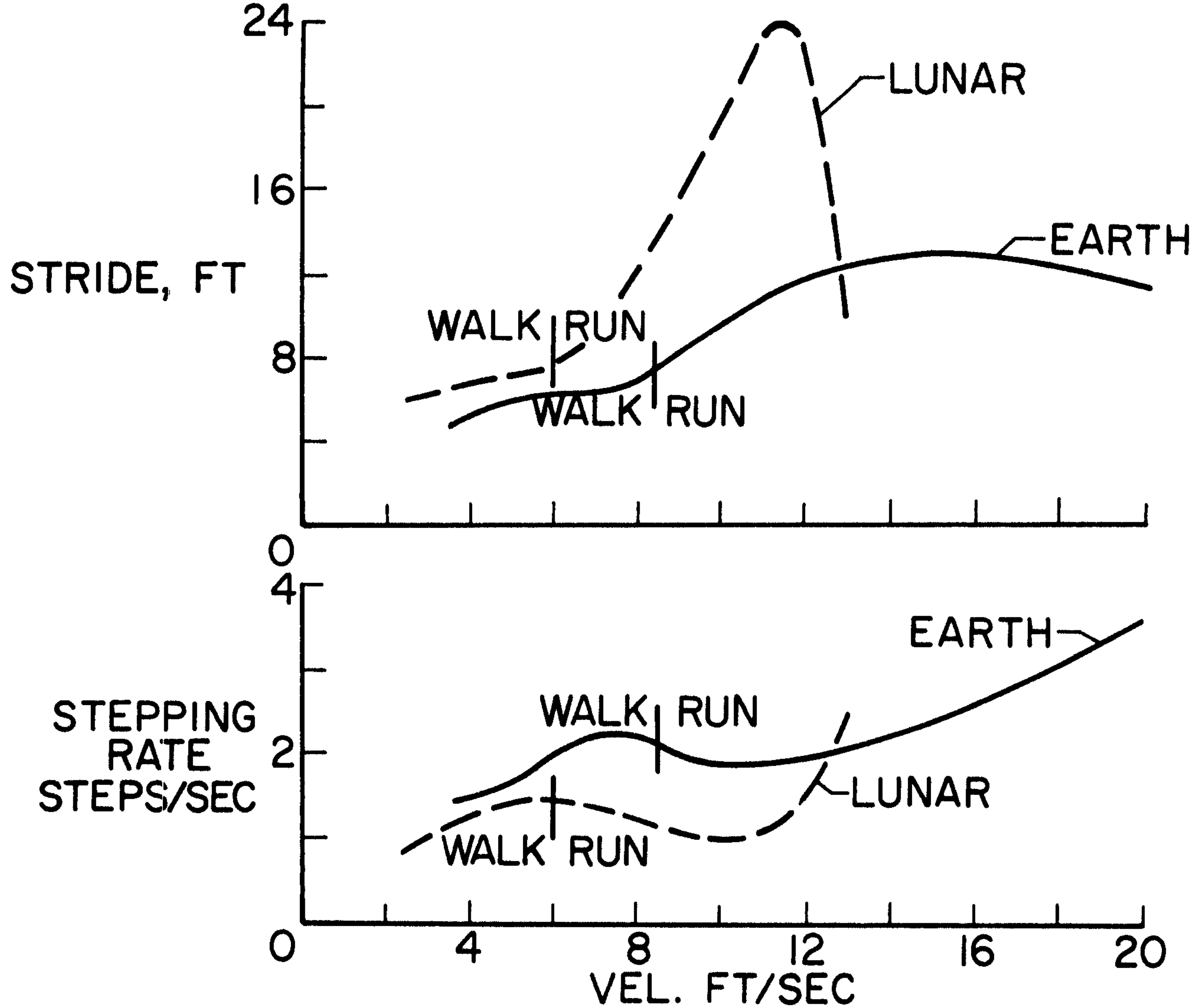

Figure 3.- Some test results obtained using the lunar walking simulator.

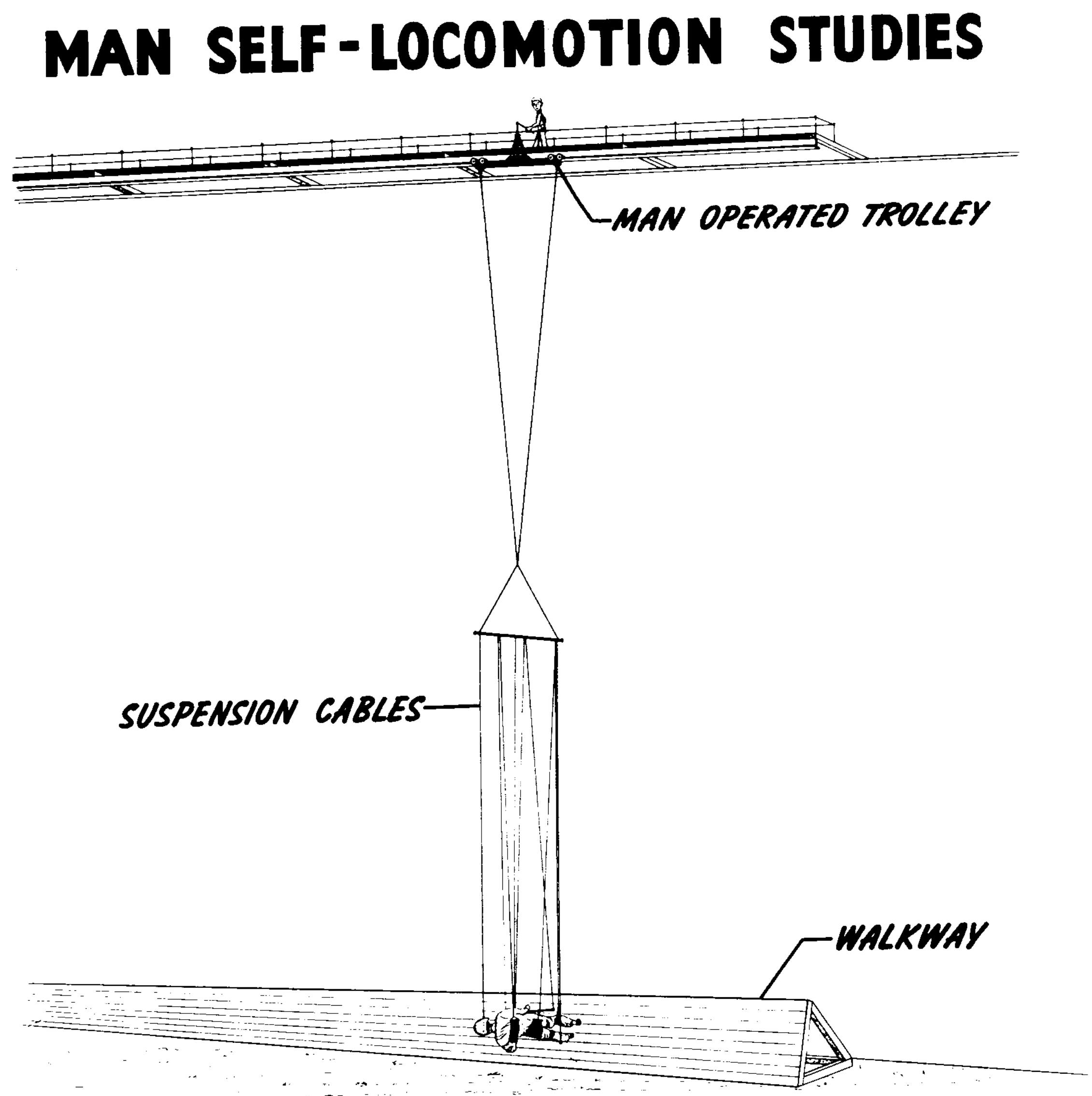

Figure 2.- Sketch illustrating the lunar walking simulator.

Figure 4.- Photograph of the rotating space station simulator.

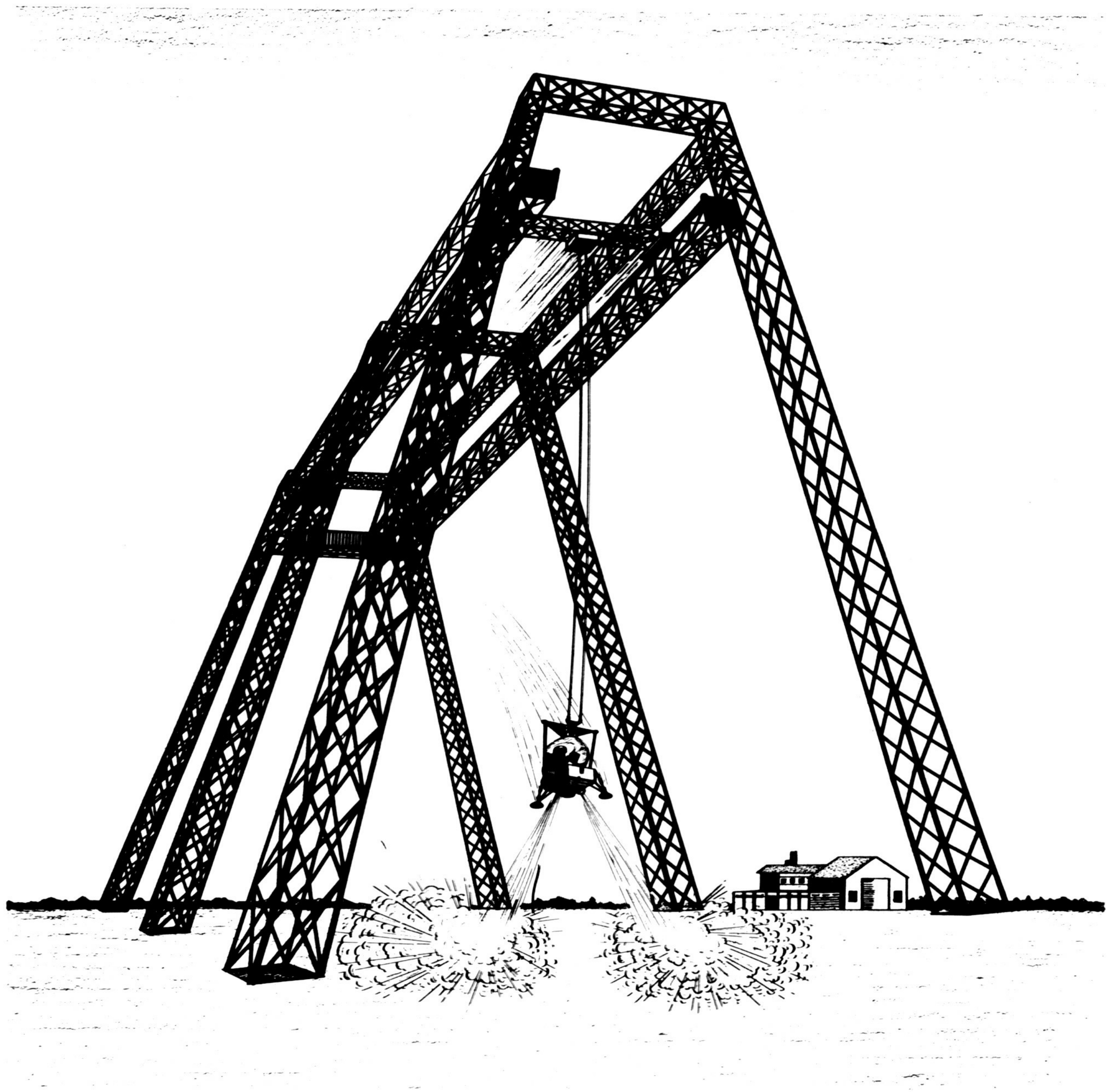

Figure 5.- Sketch of the lunar landing research facility.

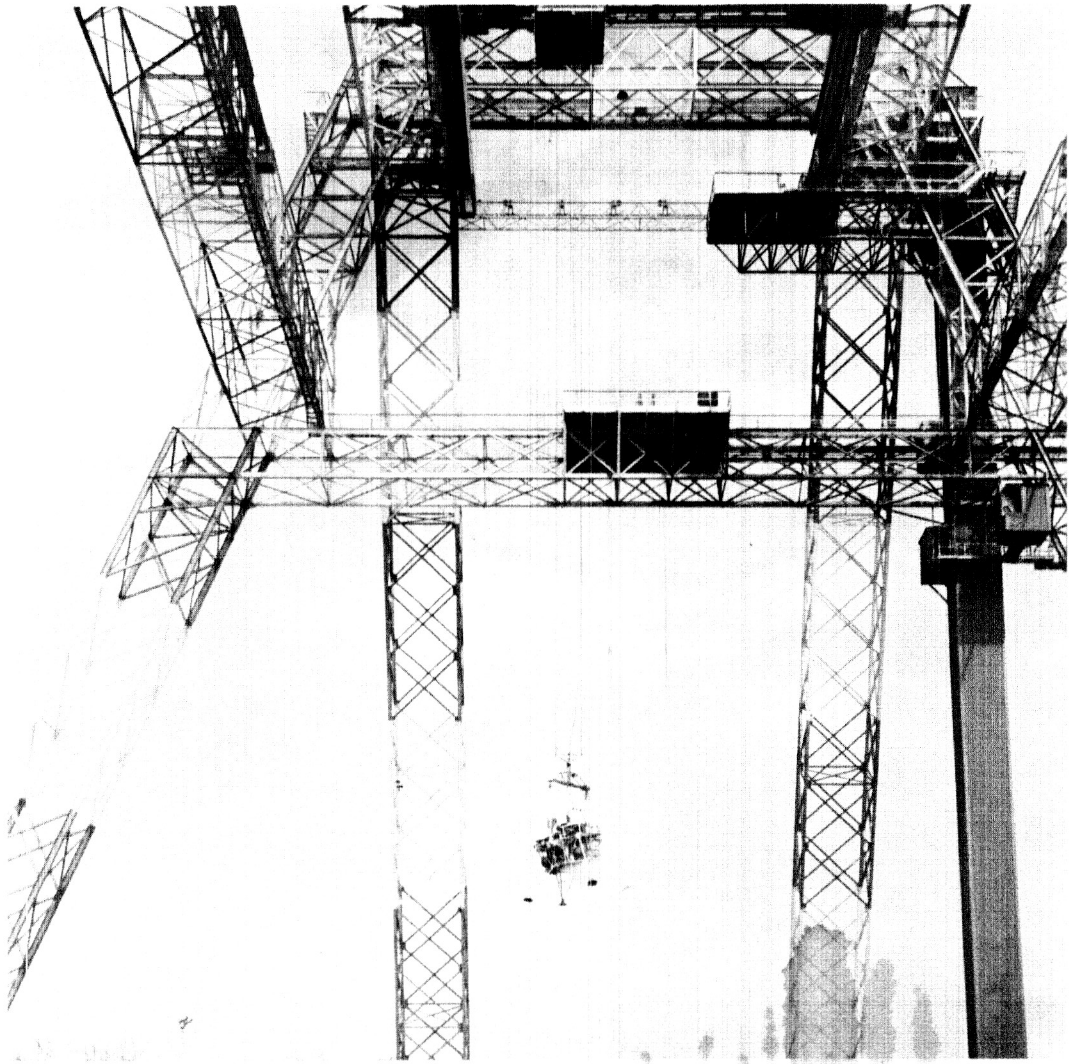

Figure 6.- Photograph of the lunar landing research facility illustrating the vehicle suspension system.

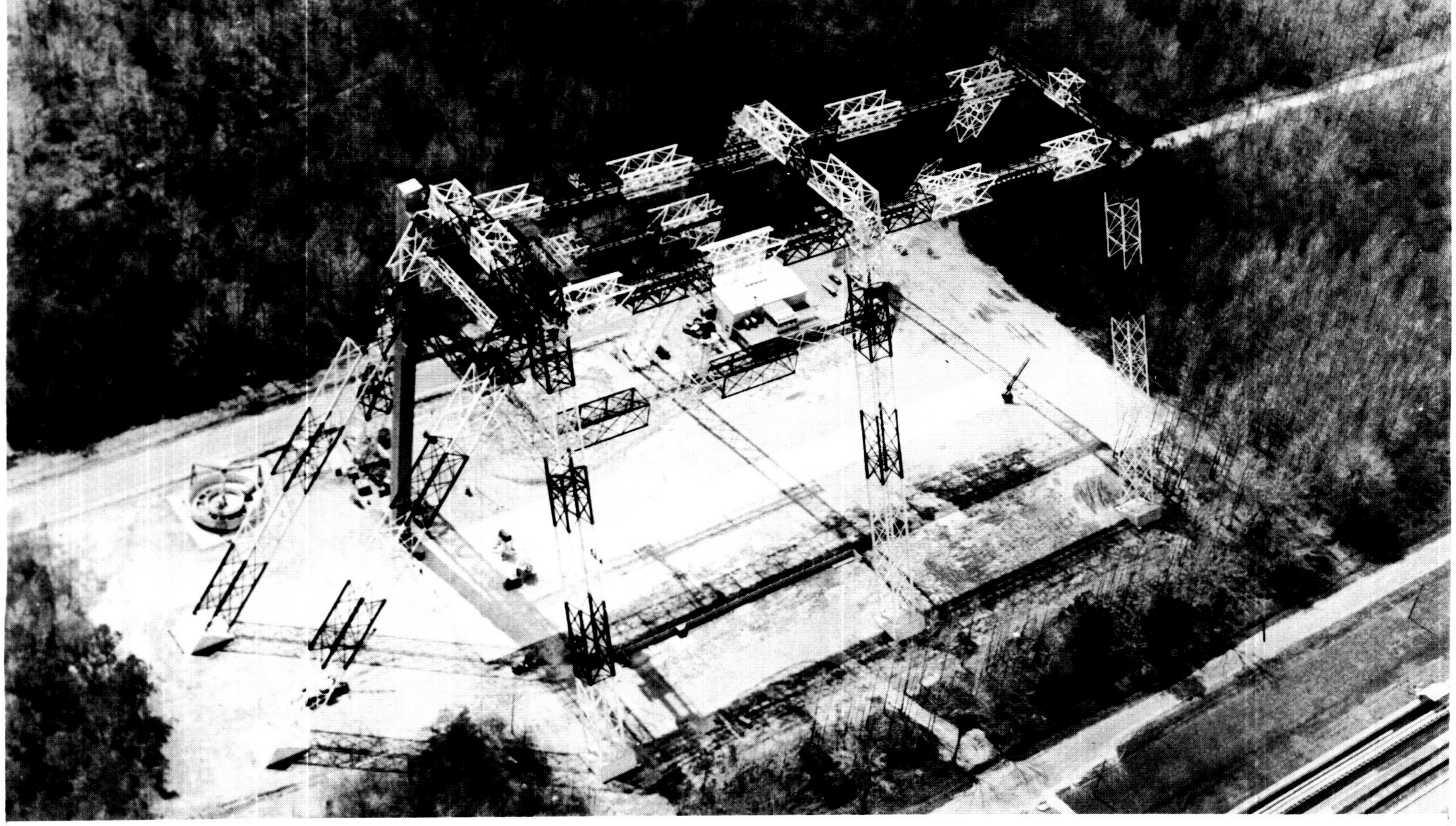

Figure 7.- Aerial photograph of the lunar landing research facility.

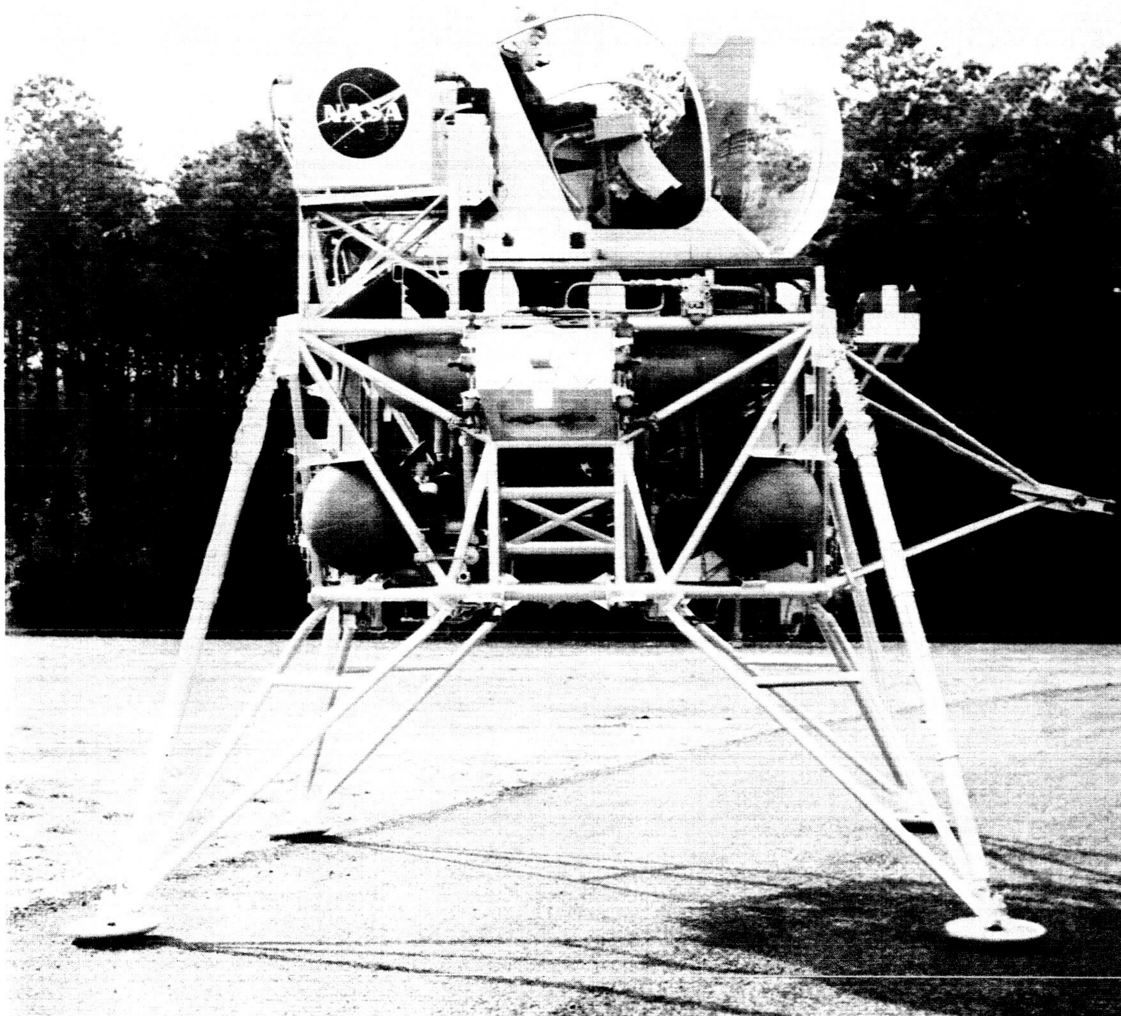

Figure 8.- Photograph of the research vehicle.

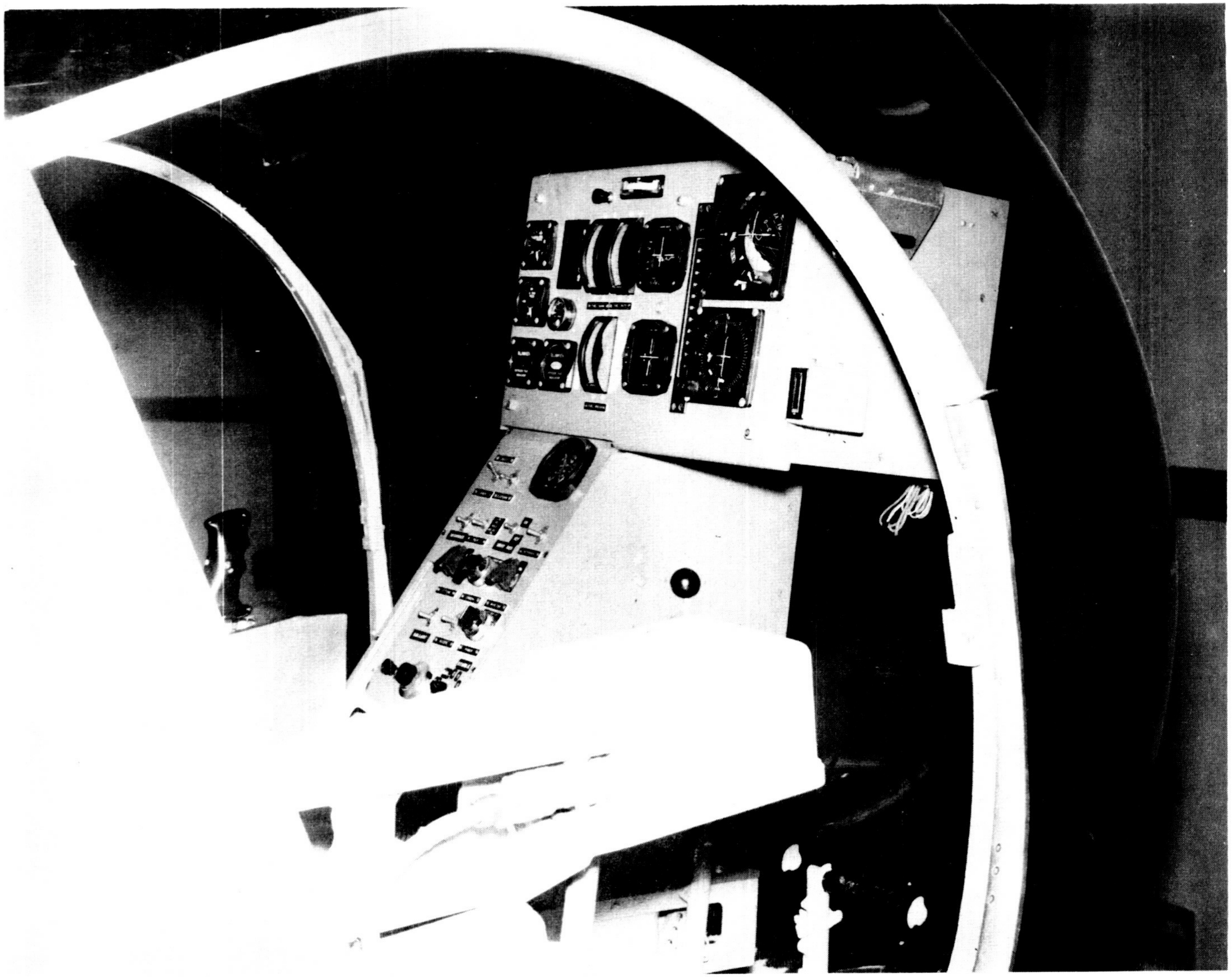

Figure 9.- Photograph of pilot's controls and instrument panel.

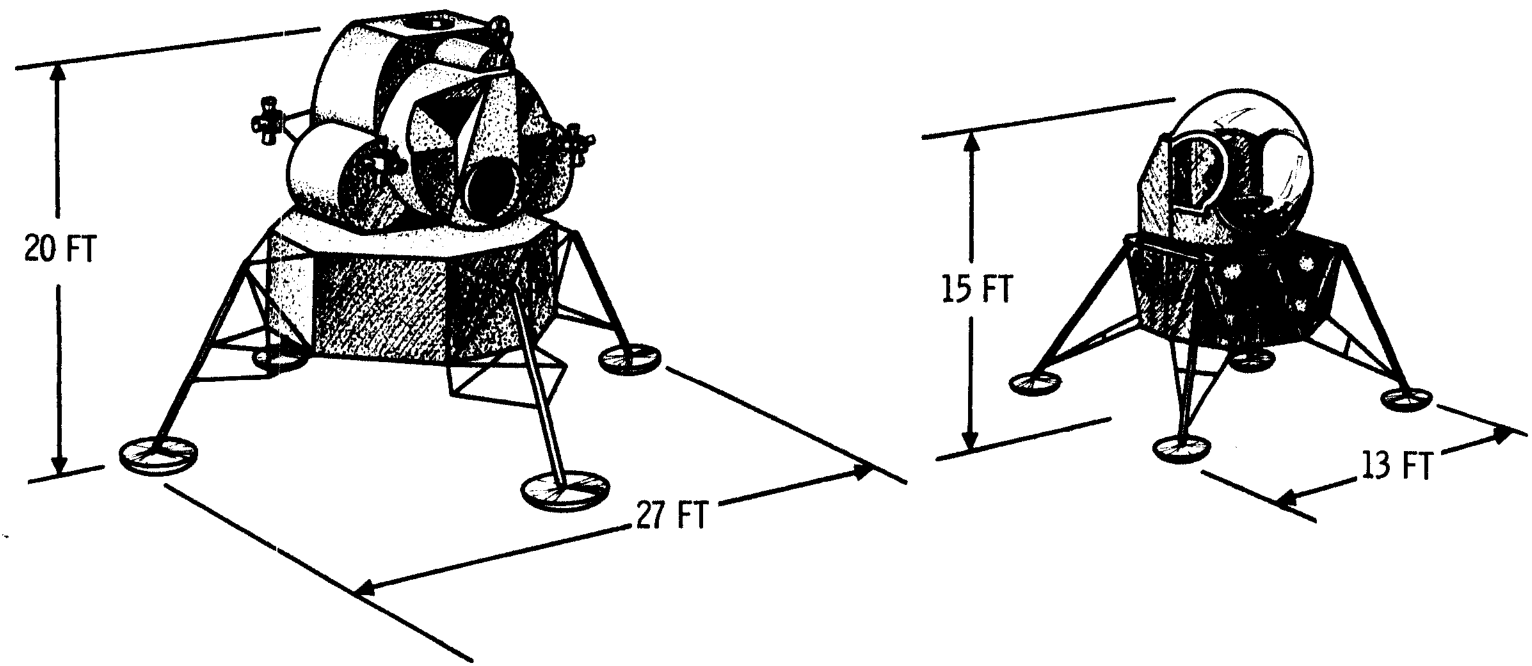

Figure 10.- Sketch illustrating the relative sizes of the Apollo LEM and the LLRF vehicle.

NASA-Langley, 1965